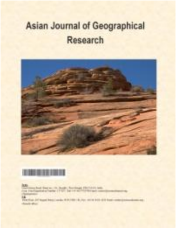

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Impact of Temperature Changes on Groundwater Levels in Nzoia River Basin, Kenya

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

Climate change poses uncertainties to the supply and management of water resources under the observed increase in surface temperatures all over Africa. The aim of this study is to assess the impact of temperature changes on groundwater levels in Nzoia River Basin. Temperature and groundwater level variability and trends has been analyzed using the parametric test of Linear regression and the non-parametric Mann–Kendall statistical test. Temperature data was obtained from the Kenya meteorological department (KMD) whereas groundwater level data was collected from Water resources management agency (WRMA). Linear regression of the annual groundwater levels in Nzoia River Basin between 2011 and 2017 revealed a decreasing trend ranging from -0.49 ft/year (Kitale Golf Club) to -0.03 ft/year (Kakamega Tande School). Mann–Kendall statistical test also showed decreasing groundwater levels for all observation wells with the results for Kitale Golf Club and Mois Bridge Quarry observation wells being statistically significant, whereas those for Kapsabet Boys High School, Kakamega Mwikalikha School, Kakamega Tande School and Busia Town Prison were statistically insignificant at 5% significance level. The highest decline in groundwater levels was observed in the upper catchment of the basin.

There are significant increases in annual tempratures for Kitale and Kakamega stations in the period 1979 – 2014. Kitale showed annual maximum temprature rising at 0.000626^{0}C/year; annual minimum temperature rising at 0.001163^{0}C/year and the annual mean temprature rising at 0.000894^{0}C/year. Kakamega had annual maximum temprature rising at 0.000771^{0}C/year; annual minimum tempratures rising at 0.000471^{0}C/year and the annual mean tempratures rising at

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0.000623^{0}C/year. Eldoret showed falling maximum temprature at - 0.00202^{0}C/year; rising minimum temperature at 0.000813^{0}C/year and falling mean temperatures at - 0.00142^{0}C/year. The results for Kitale and Eldoret stations showed statistically significant trends whereas those for Kakamega station had a statistically insignificant trend. In Nzoia River Basin, Kitale and Eldoret, annual minimum tempratures are rising faster than the maximum whereas in Kakamega it's the annual maximum tempratures that are rising faster than the minimum. Kitale and Kakamega stations showed rising annual mean temperatures whereas Eldoret showed falling annual mean tempratures. As one would expect, temperatures in Nzoia River Basin are expected to be rising; however, the case of falling temperatures recorded at Eldoret international airport might occur because this region of Rift valley has highly protected natural resources and a high forest cover is available all the year round. Another possible explanation to this could be the changing cloudness around Eldoret station. Kitale and Kakamega showed annual mean tempratures rising at about 0.1^{0}C per century and Eldoret showed mean temperatures falling at about -1.4^{0}C per century. The findings for Kitale and Kakamega stations compare well with IPCC Third Assessment Report estimated global warming rate of 0.6^{0}C during the twentieth century and other studies from the African continent and East African region.

The decreasing trend in groundwater levels in the basin appears to be linked to climate change. Increases in temperature have an impact on the hydrologic cycle because they enhance evaporation of accessible surface water and vegetation transpiration. As a result, these changes have an impact on precipitation volumes, timings, and intensity rates, as well as indirect effects on water flux and storage in surface and subsurface reservoirs. While changes in important long-term climatic factors such as air temperature, precipitation, and evapotranspiration directly affect surface water supplies, the interaction between changing climate variables and groundwater is more intricate and little understood. For efficient and long-term groundwater resource management, understanding long-term temperature variability and trends, as well as the corresponding reaction of groundwater levels, is critical. Despite the fact that groundwater level records are only available for a short period of time, they include essential information that may be utilized to establish strategies for managing the basin's limited groundwater resources.

Keywords: Nzoia River Basin; temperature; groundwater levels; trend analysis; linear regression; Mann Kendall.

1. INTRODUCTION

Several scientists, as well as the Intergovernmental Panel on Climate Change (IPCC), concur that rising global average temperatures may result in more heavy rainfall events in most parts of the globe. The global average air temperature is expected to rise by 1.1–6.4°C by 2099, according to projections [1]. The global water cycle will be accelerated, and precipitation patterns will alter [2], affecting surface runoff, evapotranspiration, groundwater recharge, and groundwater levels. Similar studies in other regions of the world have found that rising temperatures as a result of global warming will increase demand for groundwater resources, resulting in lower groundwater levels. Climate change affects the dynamic change of groundwater levels, according to a consensus established by researchers and governments [1,3]. Climate change has become a major element affecting groundwater resources through a complex process, according to a vast number of studies now available. Groundwater recharge is easily affected by climate change, according to relevant studies, and particularly global warming and rainfall reduction have been non-negligible contributors driving diminishing groundwater levels [4]. As the world's climate warms, the frequency of rainy seasons has decreased in many locations, notably in dry and semi-arid regions [5], exacerbating the shortage of groundwater resources due to reduced groundwater recharge. Groundwater recharge imbalances exist in many parts of the world. The recharge and discharge of groundwater can reach a balance under ideal conditions (stable climatic conditions, sustainable exploitation rate). The main reasons of declining groundwater levels in the Nzoia River Basin include climate change and landuse changes, as well as uncoordinated extraction of groundwater resources.

Many scientists in many regions of the world are currently studying the relationship between climate change and dynamic changes in groundwater levels. Extreme weather has a significant impact on groundwater levels, according to Hofmann et al. [6]. In shallow aquifers, Chen et al. [7] found that temperature had a greater impact on groundwater levels than rainfall. Climate change, according to Zektser et al. [8], has induced regular droughts in the region, resulting in severe groundwater overdraft and a large drop in groundwater levels. According to Panda et al. [9], the groundwater recharge deficit in dry years did not fully recover in wet years. Groundwater levels were found to be negatively correlated with temperature and positively correlated with rainfall by Almedeij et.al [10]. Other research has found that chronic climate change, as well as human activity, have a substantial impact on groundwater dynamics [11,12,13]. 78.8% of residents in the Nzoia River Basin rely on groundwater for their domestic water requirements [14]. Greater evapotranspiration and deeper groundwater resources are caused by higher air temperatures caused by increased carbon dioxide concentrations in the atmosphere [15,16]. Deeper groundwater may raise domestic water supply abstraction costs, posing a major threat to the basin's drinking water supply.

The parametric test of Linear regression analysis and the non-parametric Mann–Kendall statistical test were used in this research to examine variability and trends in temperature and groundwater levels. The Mann–Kendall test, which has been widely used in meteorology and hydrology, has become one of the most common approaches for detecting climate change trends [17]. The Mann–Kendall test was used to examine groundwater level change trends throughout multi-year climate phases in West Africa [18]. Using the Mann–Kendall test and the Sen's slope method, Tabari et al. [19] discovered similar trends in groundwater levels in Northern Iran throughout different annual and seasonal time periods. Using the Mann–Kendall test and the Sen's slope, Abdullahi et al. [20] revealed both significant positive and negative trends for the northeastern part of Peninsular Malaysia, within discrete climatic periods. According to these investigations, the method could provide more in-depth information regarding possibly stressed groundwater systems.

2. MATERIALS AND METHODS

2.1 Study Area

The Nzoia River Basin is located in Western Kenya between latitudes $1^{0}30^{'}$ N and $0^{0}05^{'}$ S and longitudes 34^{0} E and $35^{0}45^{'}$ E; and includes the nine county governments of Elgeyo/Marakwet, West Pokot, Trans Nzoia, Uasin Gishu, Nandi, Kakamega, Bungoma, Busia and Siaya (Fig. 1). The basin has a surface area of approximately 12,959 km^{2} and is drained by a river length of 334 km. The altitude ranges from 1140 to 4300 m.

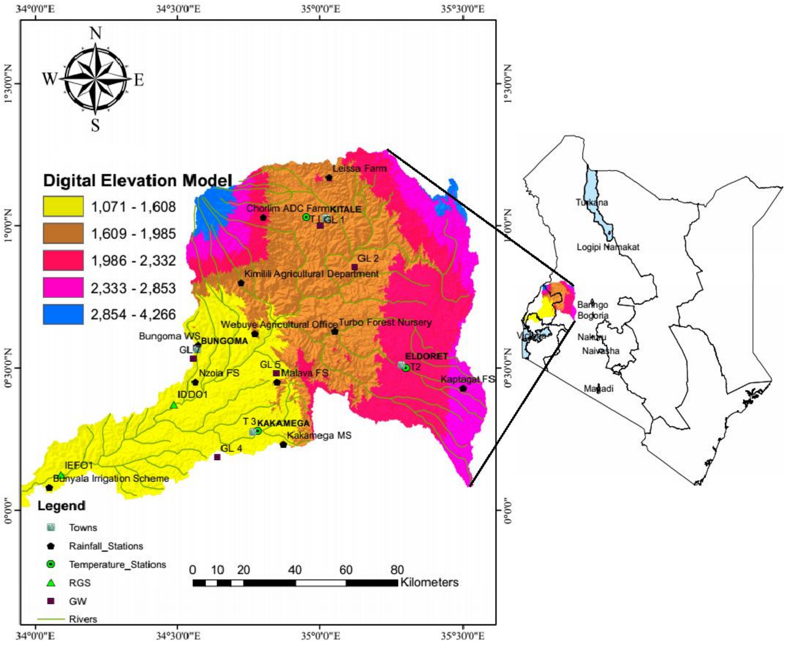


Fig. 1. Map of Nzoia River Basin, Kenya

The geology of the basin is characterized by metamorphic basement rocks, volcanic rocks and quaternary sedimentary rocks. The soil type textures range from clay (77%), loamy (9%) and sandy (14%) as described by Odwori [14]. The climate is tropical humid with annual rainfall ranging from 600 to 2700 mm. Temperatures in the highground areas of Cheranganyi and Mt. Elgon range from (4 °C -16 °C) and the semi-arid lowlands of Bunyala (16 °C -28 °C). The basin has a total population of approximately 3.7 million people. The study area has shallow aquifers tapped by boreholes and handdug wells [14].

2.2 Data Sources

Monthly maximum and minimum temperature data was collected for three stations; Kitale and Kakamega meteorological stations with data covering 35 years period from 1979 to 2014 and Eldoret international airport, 15 years period from 1999 to 2014 from the Kenya Meteorological Department (KMD), Nairobi, Kenya as shown in Table 1. Temperature data are expressed in degree Celsius (^{0}C).

The weather stations were chosen based on their quality, the length and duration of time they covered, and whether or not they had simultaneous records of meteorological data. Monthly temperatures for each of the stations were calculated by averaging daily measurements. The annual mean temperature was calculated by averaging the monthly temperatures for each year. Roman et al. [21] provide additional information on measurement uncertainty. Before the data was used, several mandatory data quality control checks were done. All variables were compared to empirical upper and lower limits, as well as systematic errors from other sources (e.g., archiving, transcription and digitalization). This can contain things like dates that don't exist. El Kenawy et al. [22], Bilbao et al. [23], Miguel et al. [24], and Roman et al. [21] provide more information on these tests.

Monthly groundwater level data were collected for seven monitoring wells; Kitale Golf Club, Mois Bridge Quarry, Kapsabet Boys High School, Kakamega Mwikalikha School, Kakamega Tande School, Bungoma Water Supply and Busia Town Prisons with data covering between 5 and 6 years period from 2011 to 2017 as shown in Table 2. The groundwater level data are expressed in feet (ft). More recently, Water resources management agency (WRMA), Lake Victoria North catchment area, regional office in Kakamega established a network of groundwater monitoring wells in Nzoia River Basin as part of the National network of groundwater monitoring sites in the country. Monitoring wells with short record durations (less than 5 years) and many gaps in their data were removed from the study of the relationship between temperature and

Table 1. Temperature stations selected for study within Nzoia River Basin, Kenya

Station Wmo Code	Station name	Latitude (^{0} N)	Longitude (^{0} E)	Altitude (m.a.s.l)
8834098	Kitale Meterological Station	1.03	34.95	1825
8935115	Eldoret International Airport	0.50	35.30	2120
8934096	Kakamega Meteorological Station	0.28	34.78	1501

Table 2. Groundwater levels observation wells selected for study in Nzoia River Basin, Kenya

Station name	Latitude (^{0} N)	Longitude (^{0} E)	Altitude (m.a.s.l)
Upper Catchment			
Kitale Golf Club	1.00141	35.00135	1800
Mois Bridge Quarry	0.85442	35.12129	1850
Kapsabet Boys High School	0.20214	35.12605	1980
Middle Catchment			
Kakamega Mwikalikha School	0.18798	34.64068	1476
Kakamega Tande School	0.48157	34.84678	1574
Bungoma Water Supply	0.57032	34.56210	1420
Lower Catchment			
Busia Town Prisons	0.44551	34.14391	1224

Table 3. Groundwater levels observation wells and the corresponding Temperature stations selected for study in Nzoia River Basin, Kenya

Groundwater level observation wells	Corresponding Temperature stations
Upper Catchment	
Kitale Golf Club	Kitale Meterological Station
Mois Bridge Quarry	Kitale Meterological Station
Kapsabet Boys School	Eldoret International Airport
Middle Catchment	
Kakamega Mwikalikha School	Kakamega Meteorological Station
Kakamega Tande School	Kakamega Meteorological Station
Bungoma Water Supply	Kakamega Meteorological Station
Lower Catchment	
Busia Town Prisons	Kakamega Meteorological Station

groundwater levels. Seven monitoring wells were selected in hydrogeological environments that commonly supply groundwater to inhabitants of Nzoia River Basin.

These monitoring wells are appropriate to examine groundwater levels because: (1) monitored groundwater levels are impacted by neither abstraction nor constructed surfaces; (2) records of groundwater levels are some of the longest available in the basin; and (3) existing temperature stations are available close to the sites. At each monitoring well, water table levels have been measured manually since 2011. Recordings have been carried out by technicians of Water resources management agency using a dipper. The timestep of the measurements in these records varies from 8 to 22 days on average. Strong seasonality is observed in groundwater-level fluctuations in monitoring wells all over the basin. Table 3 shows the Groundwater levels observation wells and the corresponding Temperature stations selected for the study on the Impact of temperature changes on groundwater levels in Nzoia River Basin.

2.3 Methodology

Trend analysis of a time series consists of the magnitude of trend and its statistical significance. For trend detection, different researchers have employed various techniques. Change detection approaches for hydrologic data are described by Kundzewicz [25]. In general, the magnitude of a time series' trend is determined using either Regression analysis (parametric test) or Mann–Kendall test and Sen’s slope method (non-parametric test).

2.3.1 Linear regression analysis

A parametric model, linear regression analysis is one of the most often used approaches for detecting a trend in a data series. By fitting a linear equation to the observed data, this model builds a link between two variables (dependent and independent). First, the data is examined to see if there is a link between the variables of interest. This can be accomplished with the use of a scatter plot. Linear regression models will not be beneficial if there appears to be no relationship between the two variables. The correlation coefficient, which runs from -1 to +1, is a numerical measure of the relationship between the variables. A perfect match is indicated by a correlation coefficient of ± 1. A value around 0 indicates that the two variables have a random, non-linear connection. The following equation describes the linear regression model in general:

$$Y = mX + C$$

Where, Y is the dependent variable, X is the independent variable, m is the slope of the line and C is the intercept constant. The coefficients (m and C) of the model are determined using the Least-Squares method , which is the most commonly used method , t-test is used to determine whether the linear trends are significantly different from zero at the 5% significance level.

2.3.2 Mann- kendall test and sen’s slope method

The Mann–Kendall (MK) test [26,27] has been used to assess trends in groundwater levels and temperature in Nzoia River Basin. It's a non-parametric test that doesn't require the data to be normally distributed to work [28]. The MK test is based on the null hypothesis (H0), which states that there is no trend, the data are independent and randomly ordered, and is checked against the alternative hypothesis (Ha), which claims that there is a trend [29]. Sen's slope (SS) estimator was used to predict the genuine slope (change per unit time) [30]. The Mann-Kendall statistics (S) are calculated using the formula [26,27,30].

2.3.3 Pearson’s product moment correlation coefficient (Pearson’s r)

Karl Pearson [31] developed Pearson's product moment correlation coefficient, or Pearson's r, from a related theory proposed by Sir Francis Galton in the late 1800s. It is the most widely used measure of association, as well as the first of the correlational measures to be devised. All subsequent correlation measures are adaptations of Pearson's equation, designed to account for any breaches of the assumptions that must be met in order to utilize Pearson's equation [32,33]. Pearson's r is a statistic that evaluates the strength, direction, and probability of a linear relationship between two interval or ratio variables. Pearson's Product Moment Correlation Coefficient - r (Pearson's r) is a value between -1 and +1 that describes the linear relationship between two interval or ratio variables. A value of 0 implies that the two variables have no relationship. A positive relationship is shown by a value greater than 0; that is, when the value of one variable increases, so does the value of the other variable. A negative relationship is indicated by a value less than 0; that is, as the value of one variable increases, the value of the other variable decreases. The stronger the association of the two variables, the closer the Pearson correlation coefficient, *r*, will be to either +1 or -1 depending on whether the relationship is positive or negative, respectively. Achieving a value of +1 or -1 means that all your data points are included on the line of best fit – there are no data points that show any variation away from this line. Values for *r* between +1 and -1 (for example, *r* = 0.8 or -0.4) indicate that there is variation around the line of best fit. The closer the value of *r* to 0 the greater the variation around the line of best fit.

It's the same as the point-biserial correlation, which is a measure of the relationship between a dichotomous (yes or no, male or female) and an interval/ratio variable [34]. Pearson's r has the advantage of being a simple way to evaluate the relationship between two variables, including whether they share variance (covary), whether the relationship is positive or negative, and the degree to which they correlate. The shortcomings of using Pearson's r are that it cannot detect non-linear correlations and may display a correlation of zero when the correlation has a non-linear relationship. Furthermore, the variables that can be assessed are limited. In addition to Pearson’s r, semipartial and partial correlation can be employed in order to estimate the relationship between an outcome and predictor variable after controlling for the effects of additional predictors in the equation."The ratio of the variance shared by two variables is called Pearson's correlation" [34]. The formular for computing (r = Pearson’s correlation coefficient) is elaborated in [32,33,34,35].

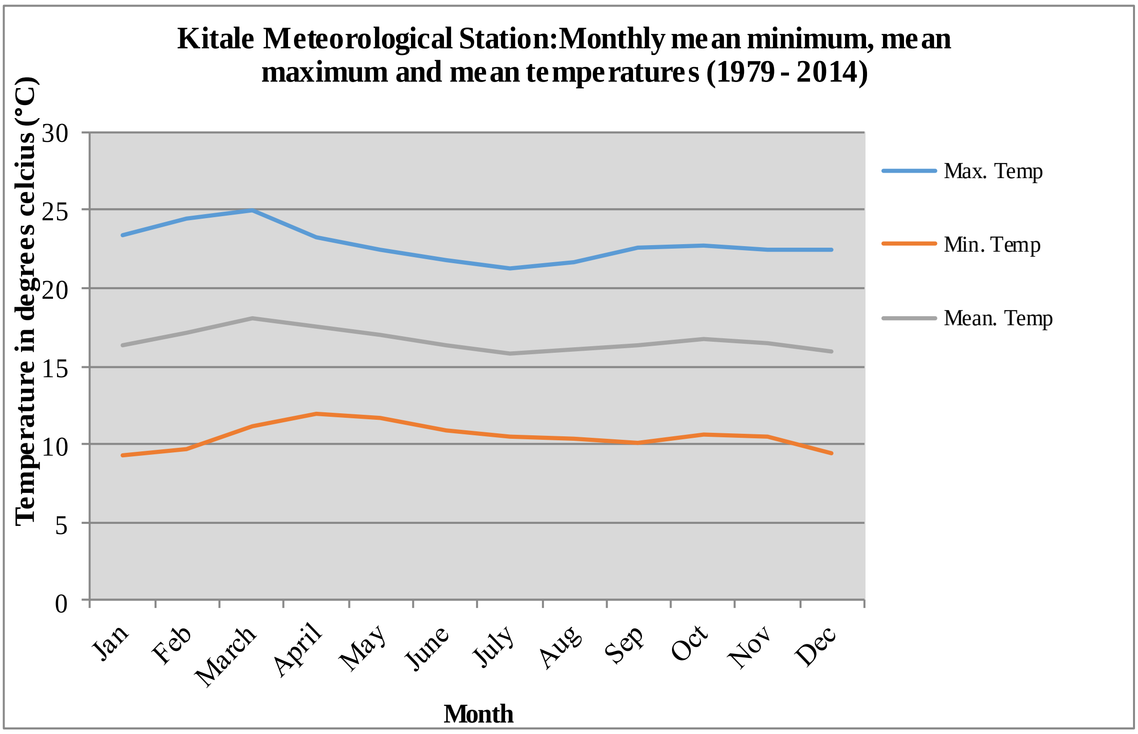
3. RESULTS AND DISCUSSION

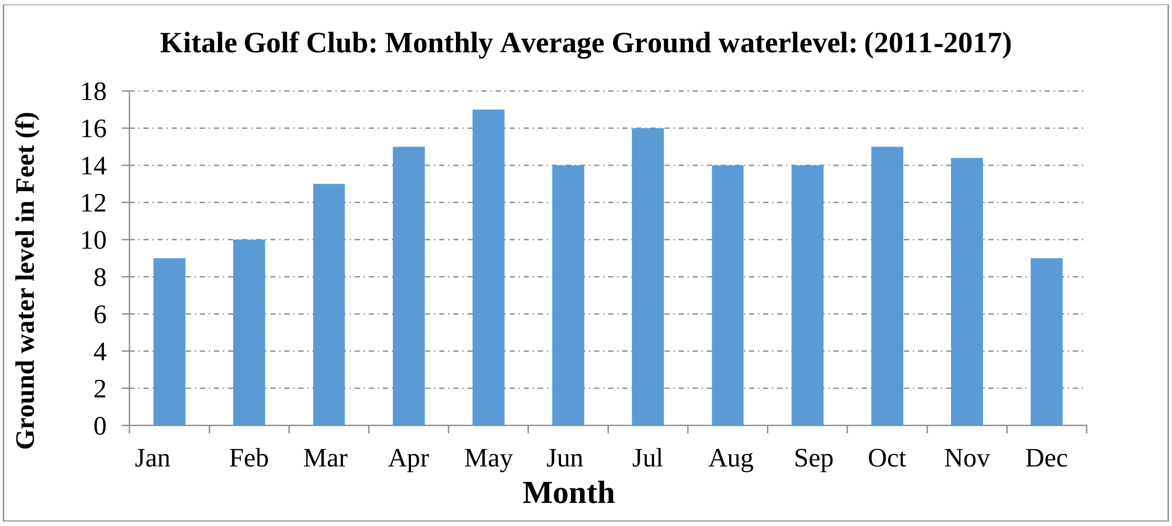
3.1 Temperature Changes and Groundwater Level Trends

3.1.1 Monthly temperature changes and groundwater levels

The monthly mean maximum temperatures at Kitale meteorological station in the period 1979 to 2014 shows a gradually declining trend from February to July. Beginning with January at 28.3^0C, the maximum temperature rises to 28.6^0C in February (hottest month of the year) and then falls gradually to 23.9^0C in July (coldest month of the year), followed by a gradual rise reaching 26.3^0C in December to repeat the annual cycle again. Monthly mean minimum tempratures for the station in the period 1979 to 2014 depict a slowly decreasing trend from January to December. Beginning from January with 10.7^0C (lowest temperature recorded in the year within the period), the temperature rises to 13.3^0C in April (highest temperature recorded in the year within the period) and then falls gradually to 10.9^0C in December to repeat the annual cycle. The monthly mean tempratures for Kitale meteorological station in the period 1979 to 2014 depicts a decreasing trend from January to December. Beginning from January with 19.1^0C, the temperature rises to 20.3^0C in March (highest temperature recorded in the year within the period) and then falls gradually to 17.9^0C in July (lowest temperature recorded in the year within the period), followed by a gradual rise to 18.8^0C in October and a fall to 18.6^0C in December to repeat the annual cycle as shown in Fig. 2.

Kitale Golf Club recorded a monthly mean groundwater level of 14.16 ft in the period 2011 – 2017. A major peak was observed in the groundwater levels at 17.2 ft in May which corresponds to the highest minimum temperatures occurring in Mar- Apr-May period and the highest mean temperatures noted in the Feb-Mar-Apr period. This coincides with the long rains period of March - May (MAM) which is marked by high minimum and mean temperatures. A minor peak in groundwater levels was seen at 16 ft in July coinciding with the lowest maximum temperatures of Jun-Jul-Aug period and the lowest mean temperatures of Jul-Aug period. This minor peak in groundwater levels at 16 ft in July is manifested by the minor rainfall peak occurring in the same period. The lowest groundwater level at Kitale Golf Club was recorded at 9 ft in December which corresponds to the lowest minimum temperatures of Dec-Jan-Feb period and the lowest mean temperatures of Dec-Jan period. This lowest groundwater level recorded at 9 ft in December coincides with the dry season which occur in the months of December, January and February (DJF).





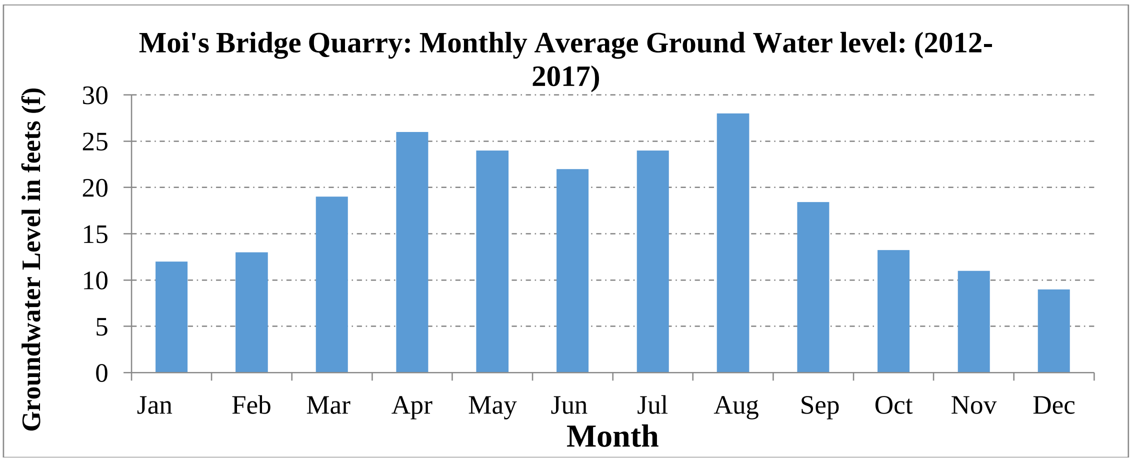
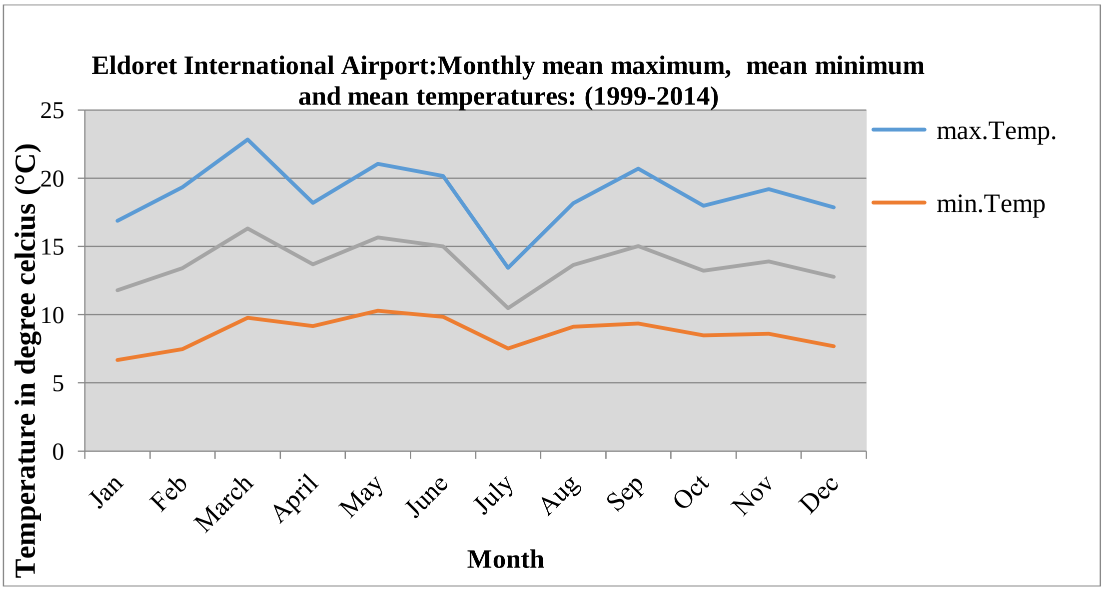


Fig. 2. Kitale Golf Club and Mois Bridge Quarry monthly mean groundwater levels compared with Kitale meteorological station monthly mean minimum, maximum and mean temperatures



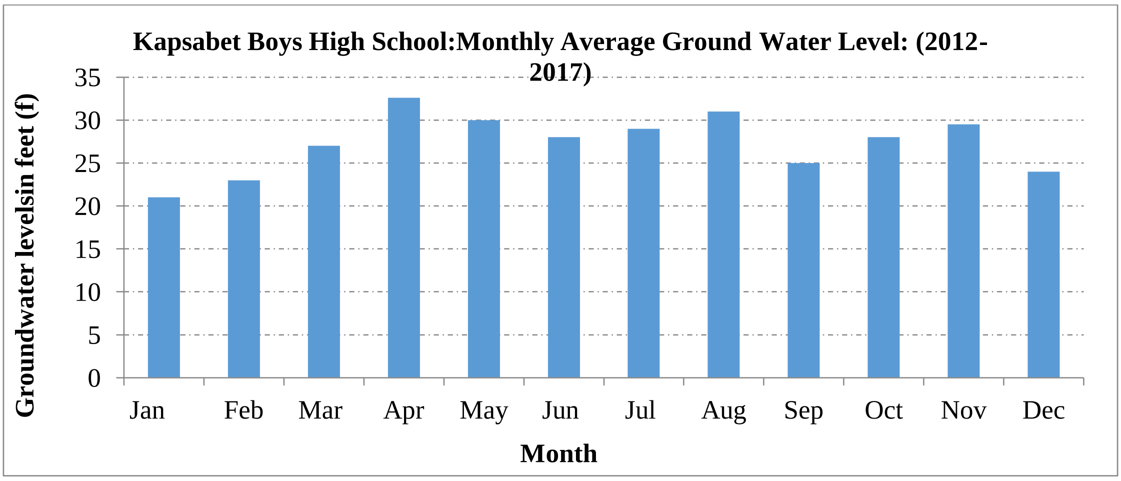


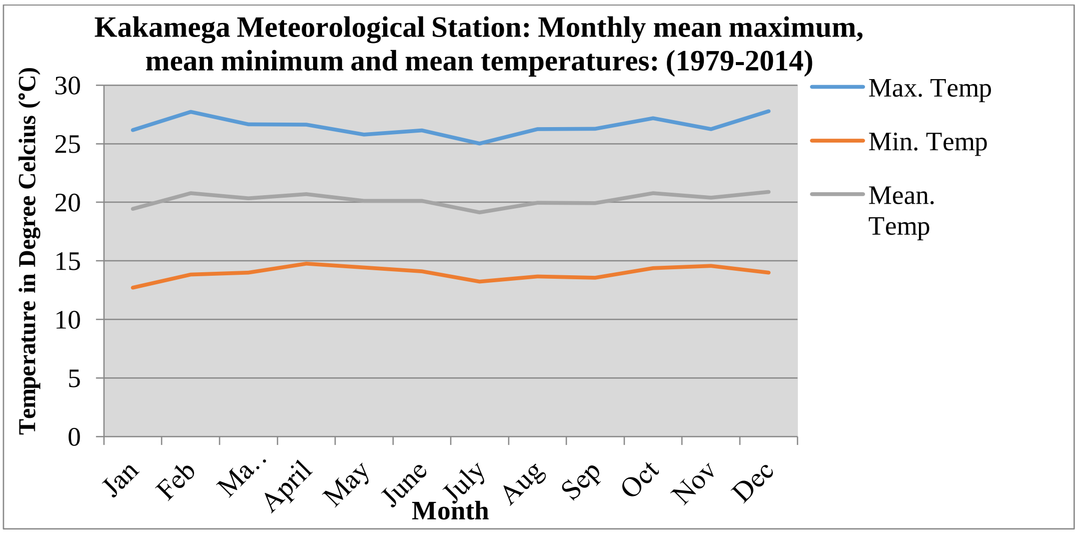
Fig. 3. Kapsabet Boys High School monthly mean groundwater levels compared with Eldoret International Airport monthly mean minimum, maximum and mean temperatures

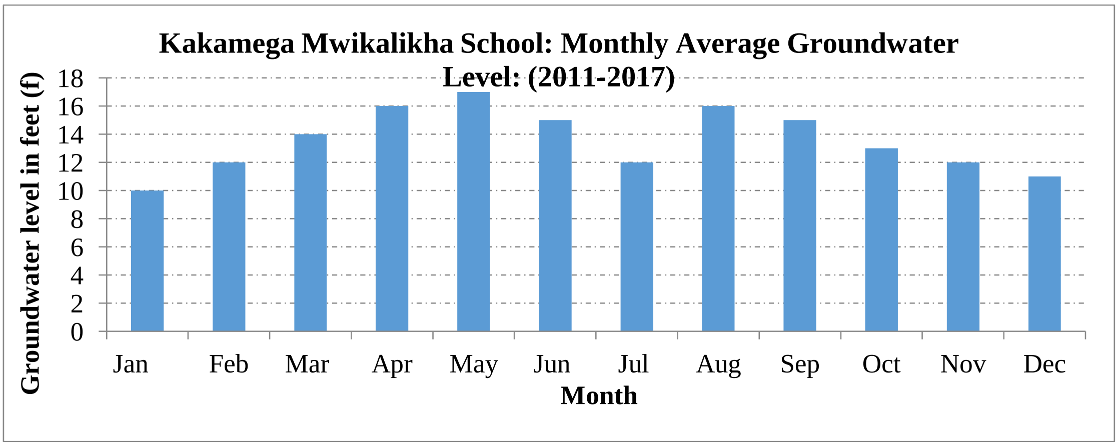
At Mois Bridge Quary, the monthly mean groundwater level recorded was 15.9 ft in the period 2012 – 2017. A minor peak was observed in the groundwater levels at 25.3 ft in April which corresponds to the highest minimum temperatures of Mar-Apr-May period and the highest mean temperatures of Feb-Mar-Apr period. This minor peak coincides with the long rains period of March - May (MAM). A major peak in groundwater levels was seen at 26 ft in August coinciding with the lowest maximum temperatures of Jun-Jul-Aug; lowest minimum temperatures of Aug-Sept and lowest mean temperatures of Jul-Aug period. This major peak in groundwater levels was seen at 26 ft in August is manifested by the third rainfall peak occuring in the months of June to August due to the modification of the regular weather pattern by the local relief and influences of Lake Victoria. The lowest groundwater level at Mois Bridge Quarry was recorded at 9 ft in December which corresponds to the lowest minimum temperatures of Dec-Jan-Feb period and the lowest mean temperatures of Dec-Jan period. This lowest groundwater level recorded at 9 ft in December coincides with the dry season which occur in the months of December, January and February (DJF).

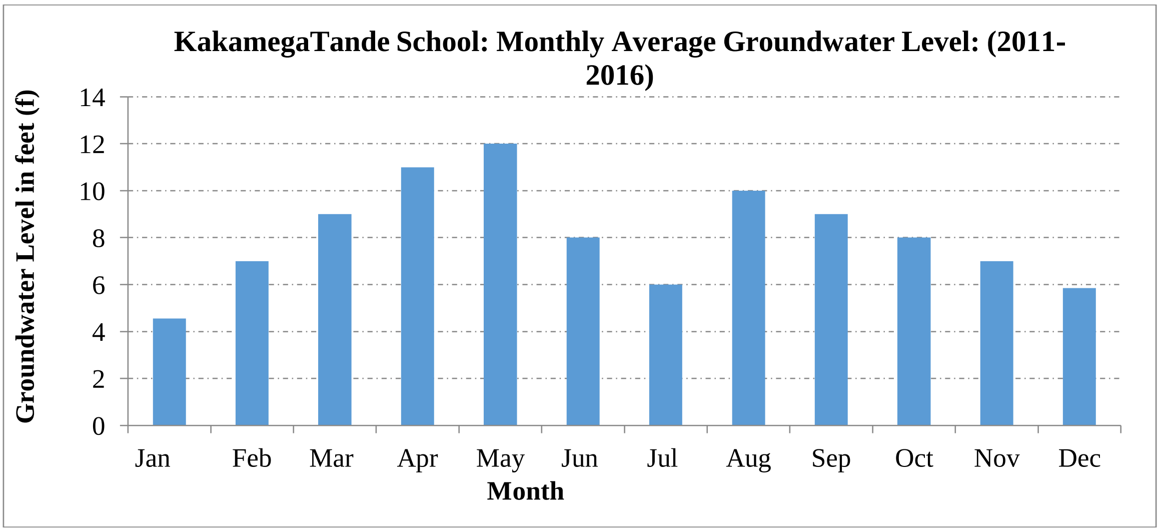
The monthly mean maximum tempratures for Eldoret international airport in the period 1999 to 2014 depicts a declining trend from January to December. The monthly mean maximum temperatures beginning with January at 16.8^{0}C, rises to 18.4^{0}C in March (hotest month of the year) and then falls gradually to 16.1^{0}C in July (coldest month of the year), followed by a gradual rise to 17.5^{0}C in October and a fall to 17.0^{0}C in December to repeat the annual cycle. The monthly mean minimum tempratures for Eldoret international airport in the period 1999 to 2014 depict a rising trend from January to December. Beginning from January with 8.6^{0}C, the temperature rises to 11.6^{0}C in April (highest temperature recorded in the year within the period) and then falls gradually to about 10.0^{0}C in July and September (lowest temperatures recorded in the year within the period), followed by a gradual rise to 10.7^{0}C in November and a fall to 9.7^{0}C in December to repeat the annual cycle. The monthly mean tempratures for Eldoret international airport in the period 1999 to 2014 depict a declining trend from January to December. Beginning from January with 16.8^{0}C, the temperature rises steadly to 18.4^{0}C in March (highest temperature recorded in the year within the period) and then falls gradually to 16.1^{0}C in July (lowest temperature recorded in the year within the period), followed by a gradual rise to 17.4^{0}C in October and a fall to 17.0^{0}C in December to repeat the annual cycle.

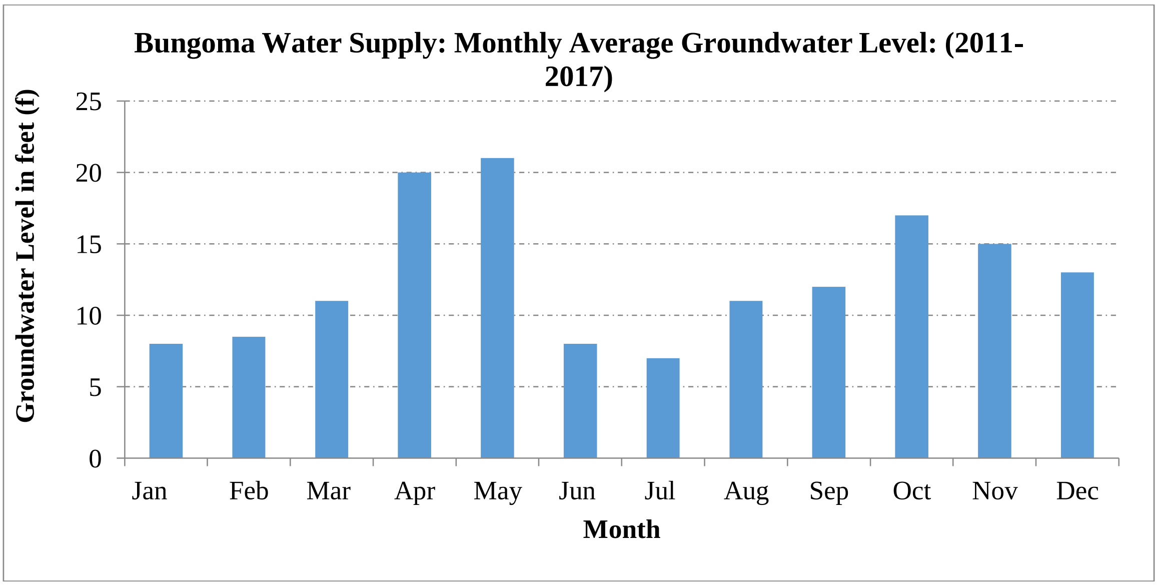
Fig. 3 shows the monthly mean groundwater level recorded at Kapsabet Boys High School as 28.4 ft in the period 2012 – 2017. A major peak was observed in the groundwater levels at 32 ft in April which coincides with the highest maximum temperatures of Mar; highest minimum temperatures of May-Jun and the highest mean temperatures of Mar period. This major peak falls within the long rains period of March - May (MAM). Minor peaks in groundwater levels were seen in May (30 ft) corresponding to the highest minimum teperatures of May-Jun period falling partly in the long rains period; and August (31 ft) corresponding to the lowest maximum, minimum and mean temperatures of Jul period. These minor groundwater level peaks of May and August fall within the third rainfall peak occuring in the months of June to August due to the modification of the regular weather pattern by the local relief and influences of Lake Victoria. Another minor groundwater levels peak is seen in November (29 ft) corresponding to the lowest maximum, minimum and mean temperatures of Dec-Jan period. This minor groundwater levels peak of November (29 ft) is due to the short rains that come in October to December (OND). The lowest groundwater level at Kapsabet Boys High School was recorded at 21 ft in January coinciding with the lowest maximum, minimum and mean temperatures of Dec-Jan period. This period falls within the dry season which occur in the months of December, January and February (DJF).

The monthly mean maximum tempratures for Kakamega meteorological station in the period 1979 to 2014 depicts a declining trend from January to December. Beginning from January at 28.7^{0}C, the temperature rises to 29.5^{0}C in February (hottest month of the year) and then falls gradually to 25.8^{0}C in July (coldest month of the year), followed by a gradual rise reaching 27.8^{0}C in December to repeat the annual cycle again. The monthly mean minimum tempratures for Kakamega meteorological station in the period 1979 to 2014 depict a slowly declining trend from January to December. Beginning from January with 13.9^{0}C, the temperature rises to 15.1 ^{0} C in April (highest temperature recorded in the year within the period) and then falls gradually to 13.57^{0}C in September (lowest temperature recorded in the year within the period). The monthly mean tempratures for Kakamega meteorological station in the period 1979 to 2014 depict a declining trend from January to December. Beginning from January with 21.3^{0}C, the temperature rises to 22.0^{0}C in March (highest temperature recorded in the year within the period) and then falls gradually to 19.7^{0}C in July (lowest temperature recorded in the year within the period), followed by a gradual rise to 20.9^{0}C in December to repeat the annual cycle.









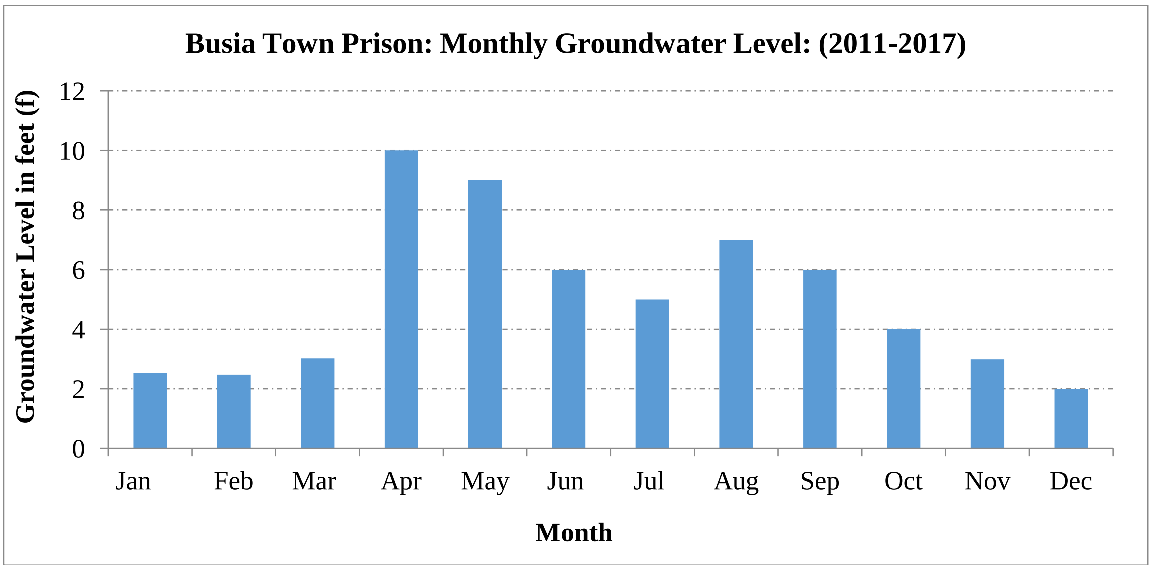


Fig. 4. Kakamega Mwikalikha School, Kakamega Tande School, Bungoma Water Supply and Busia Town Prison monthly mean groundwater levels compared with Kakamega meteorological station monthly mean minimum, maximum and mean temperatures

Fig. 4 shows the monthly mean groundwater level recorded at Kakamega Mwikalikha School as 7.9 ft in the period 2012 – 2017. A major peak was observed in the groundwater levels at 17 ft in May which coincides with the highest minimum and mean temperatures recorded in April during the long rains period of March - May (MAM). Minor peaks in groundwater levels were seen in April (16 ft) corresponding to the highest minimum and mean temperatures recorded in April and August (16 ft) in relation to the lowest maximum, minimum and mean temperatures recorded in July. The minor groundwater peaks observed in August (16 ft) is as a result of the third rainfall peak occuring in the months of June to August due to the modification of the regular weather pattern by the local relief and influences of Lake Victoria. The moderately high groundwater levels observed between October and December coincide with the highest maximum temperatures of October and December; highest minimum temperatures of October/November and highest mean temperatures of Oct- Nov- Dec period. These groundwater levels are as a result of the short rains that come in October to December (OND). The lowest groundwater level at Kakamega Mwikalikha School was recorded at 10 ft in

January coinciding with the lowest maximum, minimum and mean temperatures of January. The period coincides with the dry season which occurs in the months of December, January and February (DJF).

The monthly mean groundwater level recorded at Kakamega Tande School was 4.5 ft in the period 2011 – 2016. A major peak was observed in the groundwater levels at 12 ft in May corresponding to the highest minimum and mean temperatures of April during the long rains period of March - May (MAM). Minor peaks in groundwater levels were seen in March (9 ft) and April (11 ft) coinciding with the highest minimum and mean temperatures of April; June (8 ft) and August (10 ft) coinciding with the lowest maximum, minimum and mean temperatures of July. This is as a result of the third rainfall peak occuring in the months of June to August due to the modification of the regular weather pattern by the local relief and influences of Lake Victoria. The moderately high groundwater levels observed between September and December coincide with the highest maximum temperatures of October and December; the highest minimum temperaturs of October and November and the highest mean temperatures of October, November and December. These groundwater levels are as a result of the short rains that come in October to December (OND). The lowest groundwater level at Kakamega Tande School was recorded at 4.5 ft in January coinciding with the lowest maximum, minimum and mean temperatures of January. The period coincides with the dry season which occurs in the months of December, January and February (DJF).

Bungoma water supply recorded a monthly mean groundwater level of 10 ft in the period 2011 – 2017. A major peak was observed in the groundwater levels at 21 ft in May corresponding to the highest minimum and mean temperatures of April during the long rains period of March - May (MAM). A minor peak in groundwater levels was seen at 17 ft in October coinciding with the highest maximum and mean temperatures of October. This peak is as a result of the short rains that come in October to December (OND). The lowest groundwater level at Bungoma water supply was recorded at 7 ft in July coinciding with the lowest maximum, minimum and mean temperatures of July. This is due to the dry seasons which occur in the months of December, January and February (DJF) and in some parts, June, July, August and September (JJAS).

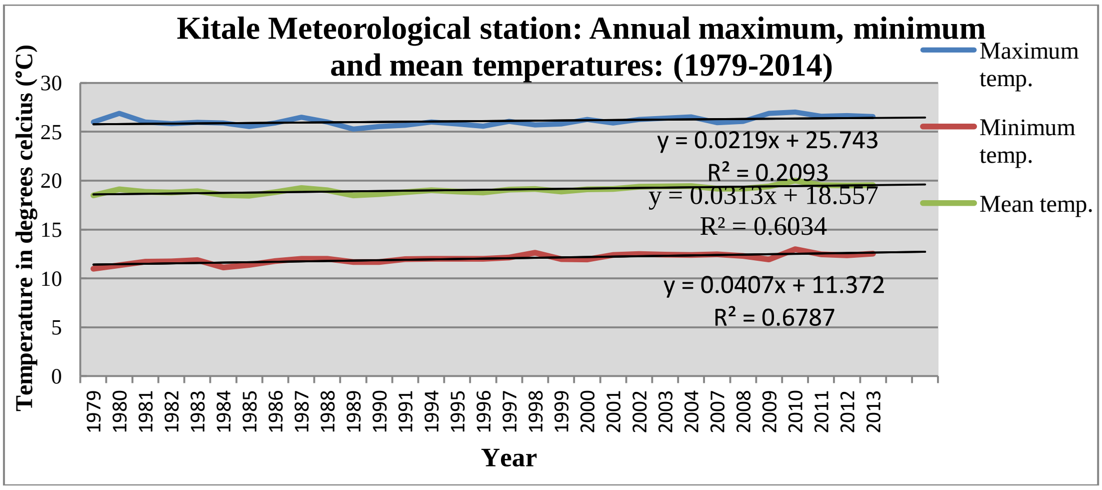
Busia Town Prison as shown in Fig. 4 recorded a monthly mean groundwater level of 3 ft in the period 2011 – 2017. A major peak was observed in the groundwater levels at 10 ft in April corresponding to the highest minimum and mean temperatures of April during the long rains period of March - May (MAM). The moderately high groundwater levels observed between August, September and October coincide with the lowest maximum, minimum and mean temperatures of July; and the highest maximum, minimum and mean temperatures of October- November – December. These groundwater levels are as a result of the modification of the regular weather pattern by the local relief and influences of Lake Victoria coupled with the short rains that come in October to December (OND). The lowest groundwater level at Busia Town Prison was recorded at 2 ft in December corresponding to the highest maximum, minimum and mean temperatures of October- November –December. The groundwater levels are as a result of the dry season which occurs in the months of December, January and February (DJF).

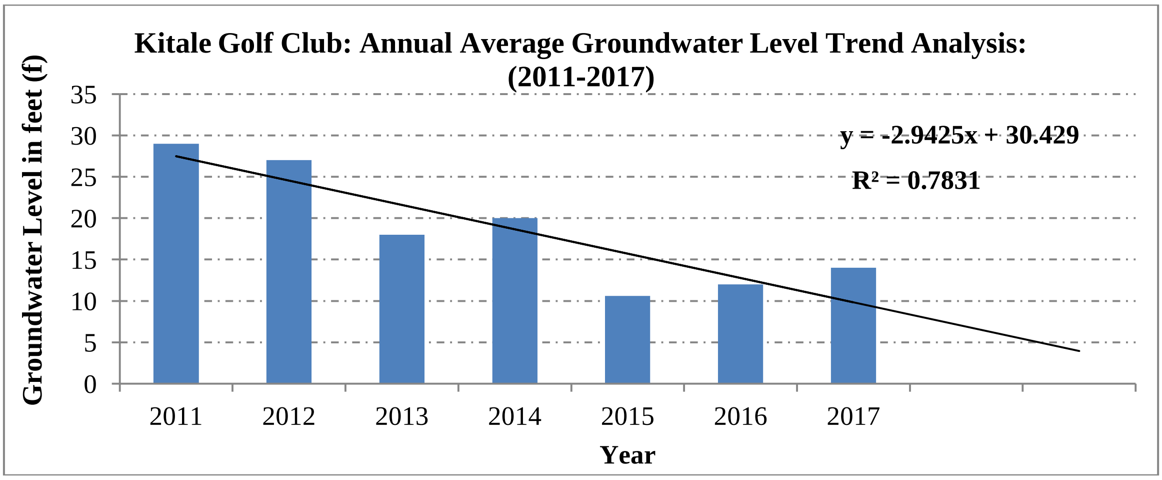
Low groundwater levels appear to be persistent in the Nzoia River Basin during the dry seasons, which occur in December, January, and February, as well as June, July, August, and September. Shallow aquifers characterize the research area, with groundwater levels responding to rainfall in relatively short periods of time. Although hydrogeologic site uniqueness and spatiotemporal variation in precipitation lead to variance in the amount and timing of reaction, all groundwater levels show rises in response to precipitation. These wells' water levels are measured throughout a same time period, allowing the measurements to represent aquifer storage at a single point in time. The monitoring wells chosen represent the physiographic zones of the Nzoia River Basin effectively. With limited pumping and artificial recharge impacts, each well represents the aquifer's local water table. Water level readings are often similar in wells that are completed in a hydraulically linked aquifer.

The study results illustrate that the maximum rainfall occurred during March – May (MAM) and very little rainfall was recorded during December-February (DJF) period. Thus the maximum runoff and infiltration are expected to occur in March – May (MAM). The monthly water table fluctuations closely follow the seasonal rainfall patterns. Groundwater level and precipitation correlations can be used to estimate aquifer vulnerability to climate change [36]. Deep groundwater production wells will exhibit considerable water level variations over time, with a varied lag in climate reaction times ranging from seconds to millions of years [37]. Because of the relatively long recharge and aquifer response period, long-term climate cycles have the greatest visible effects on groundwater levels. The El Nino Southern Oscillation (ENSO) has been demonstrated to generate the biggest changes in groundwater levels in the Nzoia River Basin. Local geology [7], land use and land cover [38], and other factors impacting infiltration and recharge rates all influence groundwater response to climate. Although the existing monitoring network in the Nzoia River Basin provides a strong framework for collecting ground water level data, the spatial distribution of wells inside specific aquifers is often uneven, with significant portions lacking monitoring wells, necessitating a network redesign. There is a clear correlation between rainfall and groundwater levels, as well as significant spatial and seasonal variances. Anthropogenic influences such as groundwater extraction for home use can sometimes disrupt this trend. Furthermore, rising extreme temperatures, which are driving high residential water supply demands, are projected to have an impact on groundwater levels in the basin. Changes in rainfall and temperature extremes, evapotranspiration, and anthropogenic groundwater extraction all have an impact on aquifer recharging and outflow [39].

3.1.2 Annual temperature changes and groundwater levels

In Fig. 5, the average annual groundwater levels at Kitale Golf Club are decreasing at the rate of 2.9425 ft/6years (0.49 ft/year) whereas at Mois Bridge Quarrry the decrease is at the rate of 1.5448 ft/5 years (0.31 ft/year). The decrease in annual groundwater levels at both Kitale Golf Club and Mois Bridge Quarrry are statistically significant. There has been small fluctuations in annual maximum, minimum and mean temperatures at Kitale meteorological station for the period 1979 - 2014 as shown in Table 4.





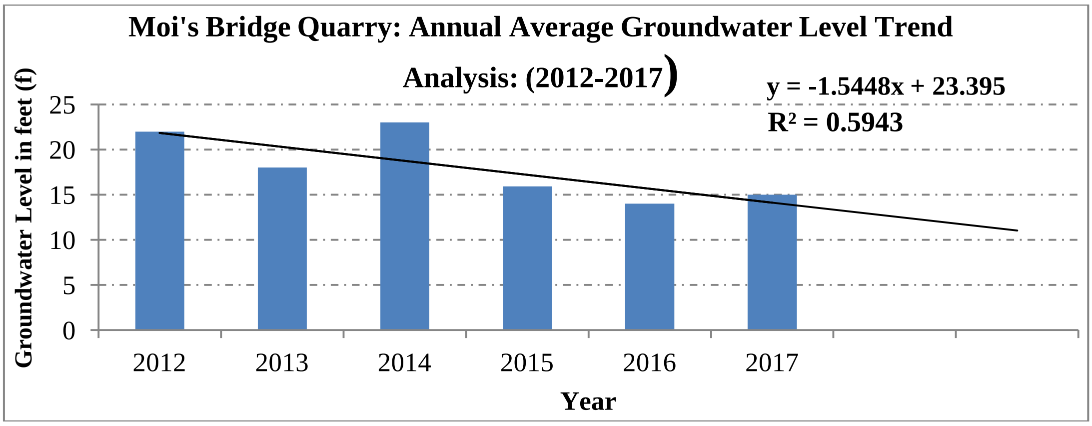
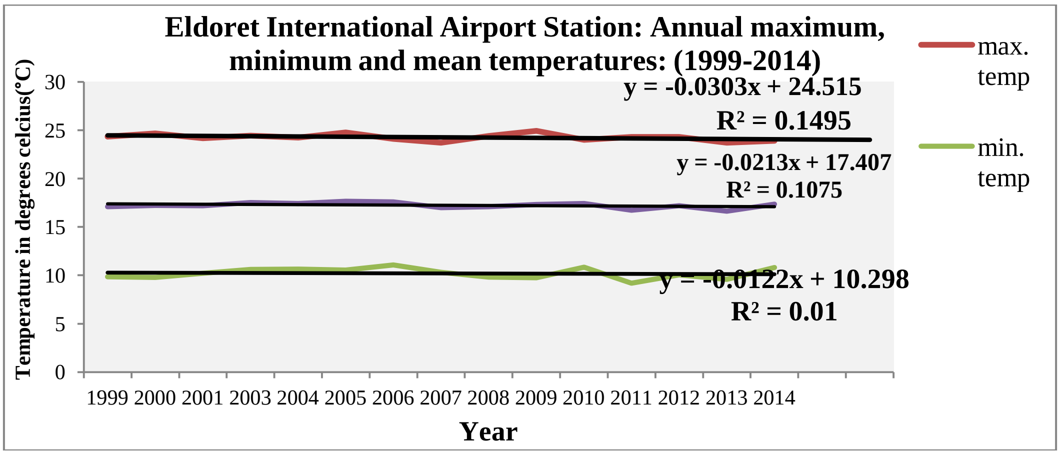


Fig. 5. Kitale Golf Club and Mois Bridge Quarry annual average groundwater levels compared with Kitale meteorological station annual average maximum, minimum and mean temperatures

Table 4. Annual temperature trends at Kitale meteorological station in Nzoia River Basin, Kenya

Annual Temprature variable	Annual trend	Rate
Maximum	Increasing	0.000626 ⁰C/year
Minimum	Increasing	0.001163 ⁰C/year
Mean	Increasing	0.000894 ⁰C/year



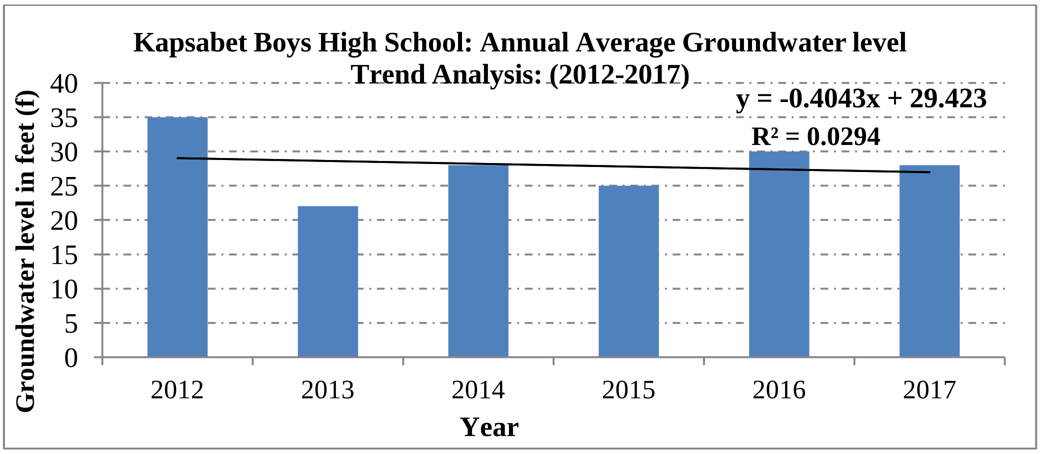


Fig. 6. Kapsabet Boys High School annual average groundwater levels compared with Eldoret international airport annual average maximum, minimum and mean temperatures

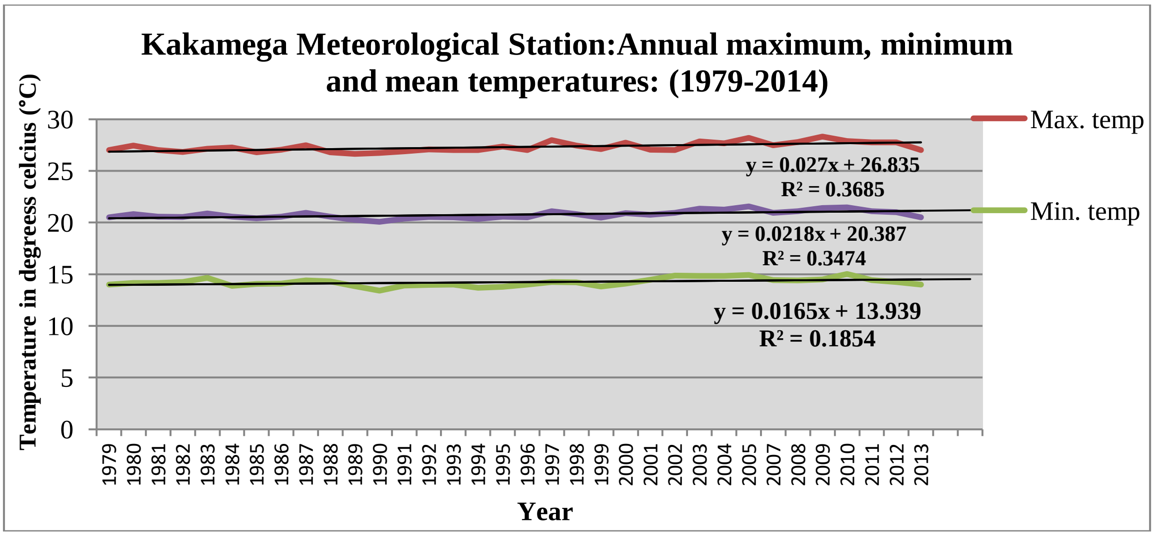
Average annual groundwater levels at Kapsabet Boys High School (Fig.6) are decreasing at 0.4043 ft/5 years (0.08 ft/year). The decrease in annual groundwater levels is statistically insignificant. There has been small fluctuations in annual minimum, maximum and mean temperatures for Eldoret international airport in the period between 1999 and 2014 as shown in Table 5.

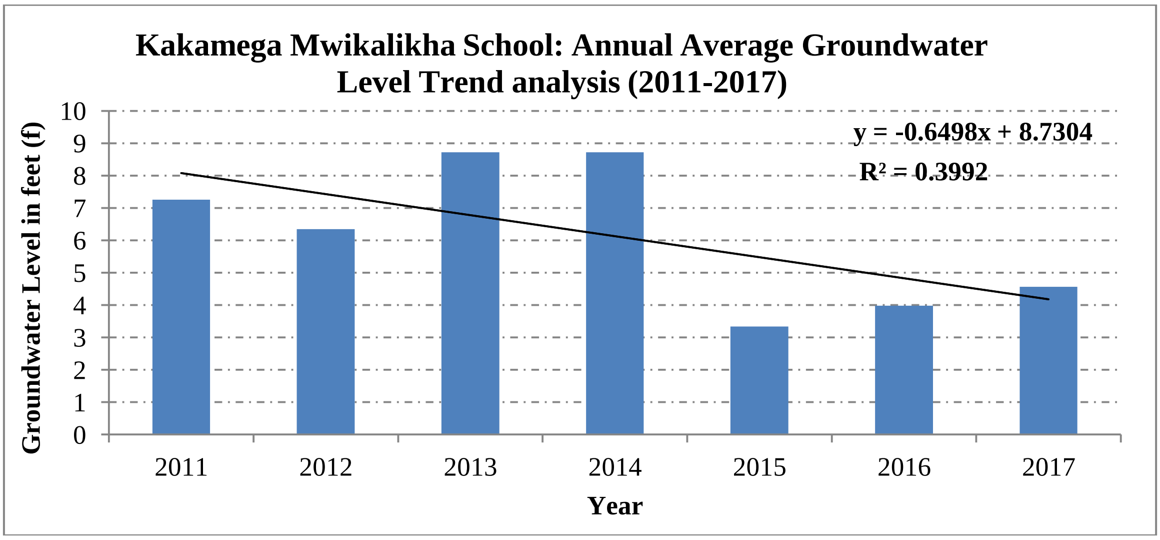
Average annual groundwater levels at Kakamega Mwikalikha Schoo (Fig. 7) are decreasing at the rate of 0.6498 ft/ 6 years (0.11 ft/year); Kakamega Tande School 0.1668 ft/ 6 years (0.03 ft/year); Bungoma water supply 0.4509 ft/ 6 years (0.08 ft/year) and Busia Town Prison are decreasing at 0.7143 ft/ 6 years (0.12 ft/year). The decrease in groundwater levels at Kakamega Mwikalikha School, Kakamega Tande School, Bungoma water supply and Busia Town Prison are statistically insignificant.

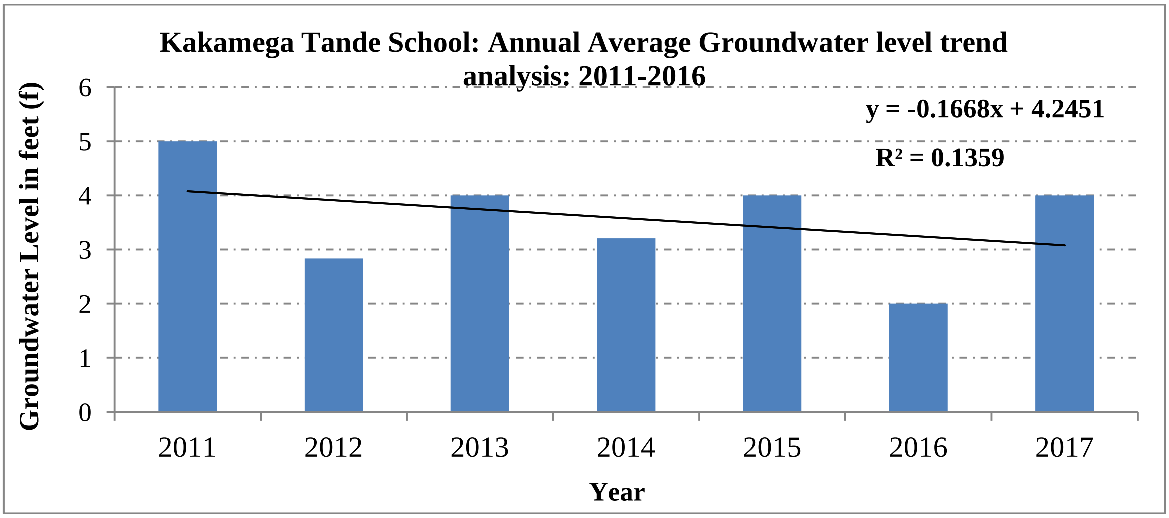
There has been small fluctuations in annual minimum, maximum and mean temperatures in the period between 1979 and 2014 as shown in Table 6.

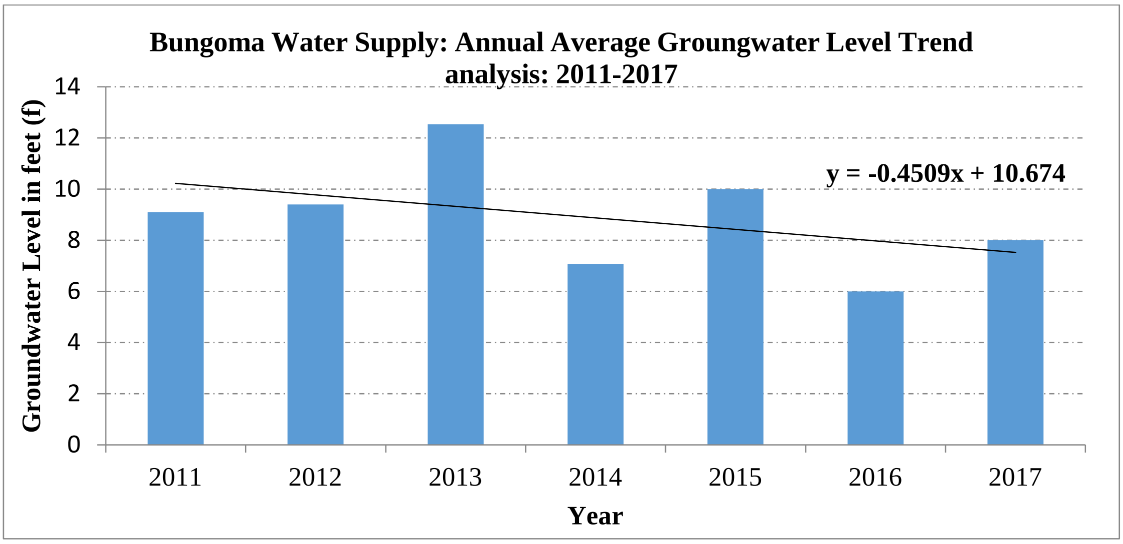
Table 5. Annual temperature trends at Eldoret International airport in Nzoia River Basin, Kenya

Annual Temprature variable	Annual trend	Rate
Maximum	Decreasing	-0.00202 ^{0}C/year
Minimum	Increasing	0.000813 ^{0}C/year
Mean	Decreasing	-0.00142 ^{0}C/year









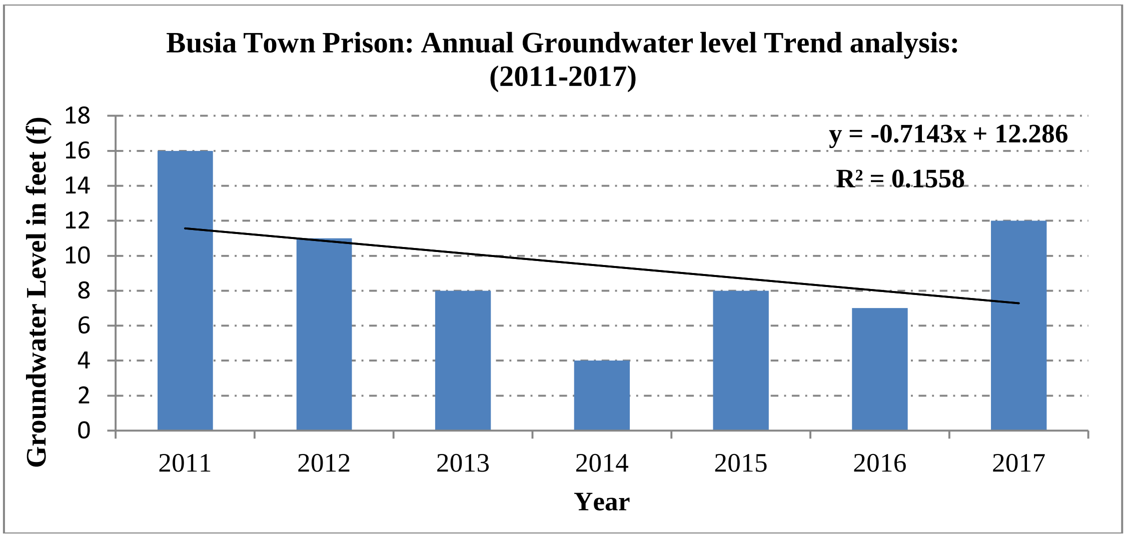


Fig. 7. Kakamega Mwikalikha School- Kakamega Tande School- Bungoma Water Supply- Busia Town Prison annual average groundwater levels compared with Kakamega meteorological station annual average maximum, minimum and mean temperatures

Table 6. Annual temperature trends at Kakamega meteorological station in Nzoia River Basin, Kenya

Annual Temprature variables	Annual trend	Rate
Maximum	Increasing	0.000771 ^{0}C/year
Minimum	Increasing	0.000471 ^{0}C/year
Mean	Increasing	0.000623^{0}C/year

Over the study period of 2011 to 2017, all wells in the study area showed a decrease in groundwater level. The complex and regionally varied relationship between groundwater pumping/withdrawal, climate change, and groundwater level is multifaceted. Groundwater depletion is associated with dry times in the climate record, while groundwater recovery is associated with wet periods. Groundwater pumping/withdrawal may decrease during a wet season, while aquifer recharge increases, alleviating stress on groundwater supplies. During a dry season, the opposite conditions and outcomes occur. Wells with varying patterns in groundwater level reduction have been discovered in close proximity, however this is due to the fact that the depths of these wells may reach multiple aquifers. Based on their own physical features, extraction rates, and recharge rates, these layered aquifers have different head level trends.

3.1.3 Mann-Kendall test on Annual groundwater levels

Annual groundwater levels data for selected stations within Nzoia River Basin under Table 2 were analyzed for trend using Mann-Kenall test and the results are shown in Table 7. When the Mann Kendall test statistics are less than 0, it indicates that groundwater level is decreasing; and when the values are higher than 0, groundwater level is increasing. The Mann Kendall test Statistic (S) indicates decreasing groundwater levels trend for Kitale Golf Club, Mois Bridge Quarry, Kapsabet Boys High School, Kakamega Mwikalikha School and Bungoma water supply observation wells whereas Kakamega Tande School and Busia Town Prison showed increasing groundwater levels trends. The results for Kitale Golf Club and Mois Bridge Quarry were statistically significant, whereas those for Kapsabet Boys High School, Kakamega Mwikalikha School, Kakamega Tande School and Busia Town Prison were statistically insignificant at 5% significance level.

Comparing Fitted Linear regression trend line and Mann-Kendall test statistic (S) results for annual groundwater levels data; Mann Kendall test statistic (S) showed two stations recording increasing groundwater levels (Kakamega Tande School and Busia Town Prison) and five stations recording decreasing groundwater levels (Kitale Golf Club, Mois Bridge Quarry, Kapsabet Boys High School, Kakamega Mwikalikha School and Bungoma water supply). On the other hand, the fitted linear regression line showed all stations recording declining ground water levels as shown in Table 8.

3.1.4 Mann- Kendall test on annual temperature

The Mann Kendall, a non-parametric test, was performed to see if there is a monotonic increasing or decreasing trend in temperature over time. In the research location, air temperature has a significant impact on the water cycle. Only two of the three stations showed a statistically significant trend in the MK test at the 5% level of significance, while the remaining one station's trend is statistically insignificant.

Annual temperatures in the Nzoia River Basin were evaluated using the Mann-Kendall test and the linear regression test. Linear trend fitted to the data was verified using the Student t-test to confirm the Mann-Kendall test results, and the results are provided in Table 9.

Table.10 shows a comparison of the results of Linear regression analysis and the Mann-Kendall test statistic (S) applied to the 3 temprature stations. Out of the 3 temperature stations, Mann Kendall test statistic (S) showed 2 stations recording increasing temperature similar to the linear fitted trend line. Both analysis methods also showed one station as recording decreasing temperature. Kitale and Kakamega meteorological stations recorded increasing tempratures whereas Eldoret international airport, recorded decreasing temperatures. The results for Kitale and Eldoret stations showed statistically significant trends whereas those for Kakamega station had a statistically insignificant trend. As one would expect, temperatures in Nzoia River Basin are expected to be rising;

Table 7. Results of the Mann-Kendall test for Annual Groundwater levels data for Nzoia River Basin, Kenya

Station name	Mann-Kendall test					
	Mann Kendall Statistic (S)	Kendall's Tau	**Var (S)**	p-value (two tailed test)	alpha	Test Interpretation
			Upper Catchment			
Kitale Golf Club	-39.000	-0.709	165.000	0.003	0.05	Reject Ho Statistically significant trend
Mois Bridge Quarry	-27.000	-0.491	165.000	0.043	0.05	Reject Ho Statistically significant trend
Kapsabet Boys High School	-10.000	-0.183	164.000	0.482	0.05	Accept Ho Statistically insignificant trend
			Middle Catchment			
Kakamega Mwikalikha School	-25.000	-0.455	165.000	0.062	0.05	Accept Ho Statistically insignificant trend
Kakamega Tande School	1.000	0.018	165.000	1.000	0.05	Accept Ho Statistically insignificant trend
Bungoma Water Supply	-3.000	-0.055	165.000	0.876	0.05	Accept Ho Statistically insignificant trend
			Lower Catchment			
Busia Town Prisons	7.000	0.127	165.000	0.640	0.05	Accept Ho Statistically insignificant trend

Table 8. Comparing Fitted Linear trend line and Mann-Kendall test statistic (S) results for Annual groundwater levels data in Nzoia River Basin, Kenya

Station name	Mann-Kendall test		Fitted Linear trend line		Mann Kendall Test Statistical Interpretation
	Mann Kendall Statistic (S)	Groundwater levels trend	Fitted Linear trend line slope	Groundwater levels trend	
			Upper Catchment		
Kitale Golf Club	-39.000	Decreasing	-2.9425	Decreasing	Reject Ho Statistically significant trend
Mois Bridge Quarry	-27.000	Decreasing	-1.5448	Decreasing	Reject Ho Statistically significant trend
Kapsabet Boys School	-10.000	Decreasing	-0.4043	Decreasing	Accept Ho Statistically insignificant trend
			Middle Catchment		
Kakamega Khwisero Mwikalikha School	-25.000	Decreasing	-0.6498	Decreasing	Accept Ho Statistically insignificant trend
Kakamega	1.000	Increasing	-0.1668	Decreasing	Accept Ho

Station name	**Mann-Kendall test**		**Fitted Linear trend line**		Mann Kendall Test
Malava Tande School					Statistically insignificant trend
Bungoma Water Supply	-3.000	Decreasing	-0.4509	Decreasing	Accept Ho Statistically insignificant trend
			Lower Catchment		
Busia Town Prisons	7.000	Increasing	-0.7143	Decreasing	Accept Ho Statistically insignificant trend

Table 9. Results of the Mann-Kendall test for Annual mean Temperature data for Nzoia River Basin, Kenya

Station name	**Mann-Kendall test**					
	Mann Kendall Statistic (S)	**Kendall's Tau**	**Var (S)**	**p-value (two tailed test)**	**alpha**	**Test Interpretation**
Kitale Meterological Station	435.00	1	3141.667	< 0.0001	0.05	Reject Ho Statistically significant trend
Eldoret International Airport	-47.000	-0.516	333.667	0.012	0.05	Reject Ho Statistically significant trend
Kakamega Meteorological Station	106.000	0.214	3800.667	0.089	0.05	Accept Ho Statistically insignificant trend

Table 10. Comparing Linear trend fitted on data and Mann-Kendall test statistic (S) results for Annual mean temperature data in Nzoia River Basin, Kenya

Station name	**Mann-Kendall test**		**Fitted Linear trend line**		Mann Kendall Test Statistical Interpretation
	Mann Kendall Statistic (S)	Temperature trend	Fitted Linear trend line slope	Temperature trend	
Kitale Meterological Station	435.00	Increasing	0.0313	Increasing	Reject Ho Statistically significant trend
Eldoret International Airport	-47.000	Decreasing	- 0.0213	Decreasing	Reject Ho Statistically significant trend
Kakamega Meteorological Station	106.000	Increasing	0.0210	Increasing	Accept Ho Statistically insignificant trend

however, the case of decreasing temperatures recorded at Eldoret international airport might occur because this region of Rift valley has highly protected natural resources and a high forest cover is always present all the year round. Another possible explanation to this could be the changing cloudness around Eldoret station.

Groundwater storage reductions are also likely to have occurred in the Nzoia River Basin as a result of the groundwater level declines found in this study. We are not aware of any studies that have quantified storage changes in the Nzoia River Basin, but this would be an essential area of future research with significant implications for the basin's groundwater sustainability. The overall reduction in groundwater levels across the basin, despite some recovery in wet seasons, as shown in this study, indicates that a sustainable groundwater management regime has yet to be created, and there are reasons for WRMA to make additional policy adjustments. Despite the increasing trend of annual rainfall in some stations of Nzoia River Basin, during 1970 and 2001, the average groundwater level from 2001 until 2017 shows a decreasing trend. Because soil infiltration capacities are being exceeded more frequently, this falling trend in groundwater level indicates that excessive rainfall intensity during the wet seasons does not provide a significant contribution to groundwater recharge [1]. To prevent further deterioration of this basin's valuable groundwater resources, we advocate the development of artificial groundwater recharge structures and the combined use of surface and groundwater. Lower groundwater levels near valley bottoms, which are groundwater discharge sites, exhibit substantially less change in groundwater decline than higher elevation groundwater levels. The reduction in groundwater levels immediately after the comletion of the rain season shows that most catchments in the Nzoia River Basin are quick at releasing groundwater. The geology and geomorphology of catchments play a major role in groundwater depletion. The higher and steeper the slope of a watershed, the faster it loses water to the low-lying and flat land.

Assuming that groundwater levels in monitoring wells are responsive to climatic phases of dry and wet seasons (i.e. decline during dry season and recovery during wet season) at a sustainable level of extraction, if groundwater levels decline in dry season but recover in wet season, this suggests some long-term resilience of the system to climate variability. In contrast, a lack of recovery in groundwater levels during the wet season (i.e., continuous groundwater decrease or no substantial upward trend) would indicate that the system is undergoing continued groundwater reduction and is vulnerable to climate change. WRMA has enacted some laws in the Nzoia River Basin to regulate the use of groundwater resources, such as mandatory borehole metering, reduced allocations, and so on; however, the overall decline in groundwater levels, as well as the lack of substantial recovery during high rainfall events in the wet seasons, suggest that groundwater decline will continue in the basin despite the existence of these laws. The overall lowering groundwater level trend in the Nzoia River Basin is important in the formulation of strategies for agricultural, industrial, and domestic water supply systems, as well as groundwater-linked ecosystems, to remain drought resilient. Droughts and broader climatic variability will render these systems more vulnerable as groundwater levels continue to drop. Climate change models predict a rise in the magnitude of droughts and increased evapotranspiration in the region, which will exacerbate the problem. Future climate change scenarios that foresee more frequent dry and wet extreme events, along with WRMA's failure to preserve groundwater resources through appropriate policy tools, would worsen groundwater reductions in the basin. Multiple climate variables, such as carbon dioxide content, temperature, solar radiation, and rainfall intensity, make it difficult to understand the drivers of groundwater dynamics [40,41,42]. Similarly, land uses (such as natural vegetation, irrigated and dryland agriculture, plantation forests, and so on) and management techniques, such as extraction rates, can all have an impact on groundwater discharge/recharge rates, and hence groundwater levels [43].

In comparison to other wells, the reduction in groundwater levels at Kapsabet Boys High School was quite gradual (-0.08 ft/year). This well looks to be in an area where local water storages could lead to localized aquifer inputs. In many circumstances, a larger range of climate variables, as well as land use and management techniques, will interact with climatic conditions, necessitating additional research to appropriately account for their impact on groundwater consumption and recharge. Access to precise long-term and high spatial resolution estimates of groundwater extraction in the basin would also help us better understand the drivers of groundwater decrease. According to recent studies, climate change, particularly climatic warming, has a significant impact on groundwater recharge [4]. As the climate warms, the frequency of wet seasons has decreased in many locations, especially in dry and semi-arid regions [5,44], worsening groundwater resource shortages due to reduced groundwater recharge. East Africa's yearly temperatures are expected to increase by 1.8 degrees Celsius to 4.3 degrees Celsius (with a mean of 3.2 degrees Celsius) between 2080 and 2099, according to forecasts. The months of June to August are expected to be the warmest [45]. This warming, according to published reports summarized in the Intergovernmental Panel on Climate Change's 2007 Assessment Report, will result in an increase in average rainfalls in the Nzoia River Basin. This rise, however, will be accompanied by greater seasonal variety in rainfall patterns, a probable increase in the occurrence of extreme precipitation events, and increasing drought frequency. Groundwater levels in the basin will be affected by these variations in temperature and precipitation patterns.

Rising temperature leads to increased evaporation and evapotranspiration which triggers higher water use by the vegetation. This could result in decreased river flows, aquifer recharge, and soil moisture content, all of which would lead to lower groundwater levels. Rising temperatures will result in greater water demand, which will result in higher abstraction rates and lower groundwater levels. Rising temperatures will also increase biological activity in the soil, resulting in less infiltration and, as a result, lower aquifer recharge, resulting in lower groundwater levels. Temperature changes have been reported to have a greater impact on groundwater level fluctuations in regions where aquifers lie close to the earth surface. This suggests that temperature has an effect on groundwater level variation. In other words, the higher the yearly mean temperature, the greater the potential influence of that temperature. As a result, with higher temperatures expected for most portions of the Nzoia River Basin in the future, annual mean temperature may play an even bigger role in determining groundwater supply. Warmer temperatures may hasten evaporation, lowering the rate of recharge to the groundwater supply and resulting in a decline in groundwater levels.

To investigate the potential effects of rising temperatures on groundwater, models based on GCMs are required. Studies have found that water usage may have a fairly consistent rate at low temperatures and average precipitation; but, when temperatures exceed a critical threshold or precipitation drops below a critical threshold, water demand increases drastically and appears to follow an exponential relationship with the two climate variables. Temperatures will rise and precipitation will rise in most regions of the Nzoia River Basin, as predicted by climate change models. Rising temperatures are likely to result in increased water consumption. As a result, increased demand for groundwater resources from industrial and domestic water users will contribute to groundwater level declines. The reaction of groundwater levels to climate change is delayed. When the weather is really dry, the dominant response time will increase. This could be because the unconfined areas of the aquifer get desaturated during protracted dry periods, changing the aquifer's transmissivity. Larocque et al. [46] made a similar observation, noting that transmissivity in a karst aquifer in France fluctuated when some conductive channels became desaturated during low water periods. If climate projections indicate warmer and drier weather in the coming years, shallow aquifers in the basin could become more desaturated and less conductive, increasing groundwater residence time and resulting in lower groundwater levels. The relationship between groundwater levels and rainfall in the basin is stronger than the relationship between groundwater levels and temperature. Temperature correlations are stronger for periods with higher temperatures than for times with lower temperatures. Under warmer climatic scenarios, temperature may play a bigger role in determining groundwater levels in the Nzoia River Basin, especially in locations where aquifers are exposed to surface evaporation.

Conjunctive uses of ground and surface water, such as using surface water for irrigation and water delivery during wet seasons and ground water during droughts, are anticipated to become increasingly important. Managed aquifer recharge, which stores extra surface water and treated waste water in depleted aquifers, could also be used to enhance groundwater storage during droughts. Indeed, using aquifers as natural storage reservoirs avoids many of the issues associated with big, manmade surface water reservoirs, such as evaporative losses and environmental damage. With the projected annual rainfall generally showing a tendency to increase slightly over the region, the annual groundwater levels are expected to rise, but due to the increased temperatures, increasing evapotranspiration coupled with increased water demand arising from the rapidly growing populations for agricultural activities, domestic use, industry and other emerging uses, groundwater levels are set to show a declining trend. Groundwater levels in each area of the basin will respond differently to changes in climate. With the temperatures getting warmer as projected in the coming years, groundwater levels are expected to decline in most areas of the basin as a result of increases in evapotranspiration and reduced groundwater recharge. Although the basin will have no significant changes in mean annual rainfalls [47], changes in seasonal distribution of rainfall may play an important role in determining changes in mean annual groundwater levels as groundwater levels and rainfall in the basin are closely correlated.

Groundwater levels have been declining in the Nzoia River Basin, as they have in many other countries, posing a threat to residential water supplies. Aquifers are over-exploited in groundwater-dependent dry and semi-arid regions, when natural replenishments are insufficient to balance groundwater withdrawals [48]. Groundwater systems have a temporal lag in responding to climatic inputs, making it challenging to effectively forecast the effects of climate change and variability [7]. Studies using General Circulation Models (GCMs) are likewise inaccurate since they do not account for groundwater [49]. Groundwater level time series are the most important source of data on the impact of hydrological and human pressures on groundwater systems [39]. Furthermore, a well-designed monitoring network can provide policymakers with information on how to manage groundwater resources sustainably. Many places of the world have been unable to conduct groundwater evaluations because maintaining an adequate network of monitoring wells is both labor-intensive and costly [50]. There is very little information available on the international level about trends in water-table levels and their possible links to extremes of important climatic variables like rainfall and temperature.

Groundwater levels must be measured and analyzed in order to sustain groundwater supply. Groundwater monitoring systems, as well as strong institutional support, are critical for acquiring, compiling, and analyzing the data required to guarantee that groundwater development occurs in tandem with effective resource evaluation and management [51]. Because groundwater responds much more slowly to changes in meteorological conditions than surface water, it has the greatest potential for coping with and minimizing the implications of climate change on domestic water supply in the Nzoia River Basin. Groundwater, as a result, acts as a natural buffer against the effects of climate change and fluctuation, such as drought [52]. According to Bates et al. [53], the biggest mystery is on how climate change will influence groundwater and what resources are now available to support adaptation plans in both developed and developing countries. Because monitoring networks are often restricted and it is difficult to regionalize point-based measurements, many African nations with significant groundwater depletion problems have minimal knowledge on the spatial and temporal variability in groundwater storage [54,51]. Despite the importance and potential of groundwater in the Nzoia River Basin, there have been few direct measurements of groundwater changes over time to support scientific decision-making and planning for the resource's long-term utilization until recently, when WRMA began the process.

The signal for groundwater-level fluctuations in both the spatial and seasonal settings is explained by analyzing time series from individual monitoring wells that contain information on both climatic and anthropogenic pressures. Although groundwater-level fluctuation is more of a location-specific reaction to recharge and discharge at first, the persistent tendency gradually extends across the entire system through inter-aquifer leakage. The aquifers are hydraulically linked, and the trends are interdependent, according to the various spatial patterns of the trends.

The volume and duration of effective rainfall, which permits groundwater recharging in a given topography and hydrogeological context, are believed to have reduced principally due to rainfall extremes in the basin, as observed in terms of drought and flood years throughout the research period. This is evident, as the basin's groundwater levels have continued to plummet year after year. When seasonal groundwater levels in one year match those in the previous year, it means that the current year's recharge is insufficient to compensate for the prior year's drawdown. Groundwater storage has been diminished in the Nzoia River Basin due to an over-reliance on groundwater for residential water supply and other requirements, with little or no replenishment from recharge. This scenario is aggravated when the drawdowns accumulate as a result of multiple drought events, as is currently common in the basin. Furthermore, due to increased crop water demands and home water supply requirements, the broad increase in temperature is believed to have put a strain on groundwater resources. Groundwater levels have declined across the basin, but extreme weather occurrences (rainfall and temperature extremes) have increased, according to the trend results. If the observed patterns in climate factors persist into the coming decades, there will most likely be a shortage of groundwater due to the projected increase in human demands on groundwater. Future research in the watershed is needed to adequately define groundwater level trends and climatic extremes. Although groundwater reductions is now a worry in many parts of Africa, a general lack of effective long-term in situ groundwater level measurement and trend analysis precludes many river basins from comprehending the dynamics of these systems. This is especially disturbing in light of future climatic uncertainty. Despite WRMA's focused policy interventions, groundwater decrease is still visible in the Nzoia River Basin, and it is projected to persist and become more widespread as a result of potential climate change. To preserve the long-term viability of this essential resource in the basin, policymakers, groundwater users, and management must collaborate in planning.

3.2 Factors Influencing Groundwater Levels in Nzoia River Basin

The primary factors influencing groundwater levels in Nzoia River Basin are climate change (rainfall, temperature), lithology of the aquifer, human factors such as land use and land cover changes, exixting water policy, regulation, governance and management, increased groundwater pumping/withdrawal, construction of reservoirs and sunshine duration.

3.2.1 Climate Change (rainfall and temperature)

Climate change has been seen in the Nzoia River Basin, with an upward trend in temperature and both upward and downward trends in precipitation. The rise in water vapor capacity is due to the rising trend in mean annual temperature. The loss of groundwater through evaporation is exacerbated by increased evaporation induced by rising temperatures, resulting in the observed falling groundwater levels. One of the most important sources of groundwater is precipitation. Groundwater levels in the Nzoia River Basin are extremely vulnerable to high rainfall, so maximizing the use of heavy rainfall and flood resources could be an effective approach of recharging groundwater resources.

3.2.2 Human activities

Changes in land use and land cover, as well as increasing groundwater pumping and withdrawal for domestic, industrial, and agricultural purposes, have an impact on the natural balance of groundwater resources, resulting in altered dynamics. If the amount of groundwater withdrawn equals the amount of groundwater recharged, and the groundwater level is lower than the original average water level, bigger changes will occur, but the groundwater level will not continue to decrease [55]. If the amount is too big and surpasses groundwater recharge, the groundwater level will continue to fall, resulting in an increase in the thickness of the unsaturated zone, which has resulted in an increase in the time it takes for the groundwater level to respond to precipitation. The response time of the groundwater level to precipitation will increase further if overexploration remains constant or increases. Previous research has looked into the relationship between the lag time of two parameters and the thickness of the unsaturated zone [56,57]. For example, Zhang et al. [57] demonstrated through tests that when the unsaturated zone thickness exceeds the diving evaporation limit, the infiltration rate drops as the unsaturated zone thickness increases, and the temporal delays rise. Groundwater policy, legislation, governance, and management in the Nzoia River Basin are all essential factors affecting groundwater resources.

3.2.3 Lithology of the aquifer

Besides the impact of human activities, the lithology of the aquifer is another key component influencing the groundwater-precipitation interaction [58,59]. Various lithologies of the aquifer have different hydrogeological properties, such as hydraulic conductivity, precipitation infiltration recharge coefficient, specific yield, and so on. Precipitation can easily recharge groundwater, while subterranean runoff in bedrock fissure aquifers swiftly discharges water into rivers. As a result, groundwater responds to precipitation more quickly, although there is no visible change in water level. Where the temporal lag and groundwater level variation are all largest, indicating that when the groundwater is recharged by precipitation, the hydraulic gradient is not obviously increased because it is far away from the discharge area, and the increased intensity of groundwater runoff is not significant, then the water level will rise.

4. CONCLUSION

In this study, we have investigated air temperature variability and trends for three stations and groundwater level fluctuations for seven monitoring wells in Nzoia River Basin. Kitale and Kakamega stations showed rising annual mean temperatures whereas Eldoret showed falling annual mean tempratures. As one would expect, temperatures in Nzoia River Basin are expected to be rising; however, the case of falling temperatures recorded at Eldoret international airport might occur because this region of Rift valley has highly protected natural resources and a high forest cover is present all the year round; and another possible explanation could be the changing cloudness. Kitale and Kakamega showed annual mean tempratures rising at about 0.1^0C per century and Eldoret showed mean temperatures falling at about -1.4^0C per century. The findings for Kitale and Kakamega stations compare with IPCC Third Assessment Report estimated global warming rate of 0.6^0C during the twentieth century and other studies from the African continent and Eastern African region. The results clearly indicate that changes are occurring in temperature within the basin this could affect groundwater levels. According to historical groundwater level records, groundwater levels in the basin decreased between 2011 and 2017. Groundwater level reductions are evenly distributed across the basin, but are most pronounced in upland recharge zones (upper Nzoia catchment). The findings show significant negative trends in water storage over multiple decades, but without understanding aquifer storativity, rates of groundwater depletion cannot be deduced from groundwater level variations. Increased energy consumption for pumping, the need for deeper wells, and irreversible repercussions such as permanent aquifer compaction and land subsidence may all occur as groundwater levels fall. Groundwater level changes are caused by a variety of factors that vary in time and space across the basin. Changes in temperature (i.e., climate change) are a clear controlling effect on groundwater levels. This study's findings can be utilized to pinpoint areas of the basin where a more extensive aquifer or sub-aquifer scale analysis is needed to better groundwater management. We recommend that WRMA consider establishing temperature recording stations near groundwater level monitoring wells to improve the accuracy of the temperature-groundwater level correlation. Groundwater level records include vital information on the long-term behavior of aquifers that hasn't been examined in depth, but could be useful to our water managers in the future.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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